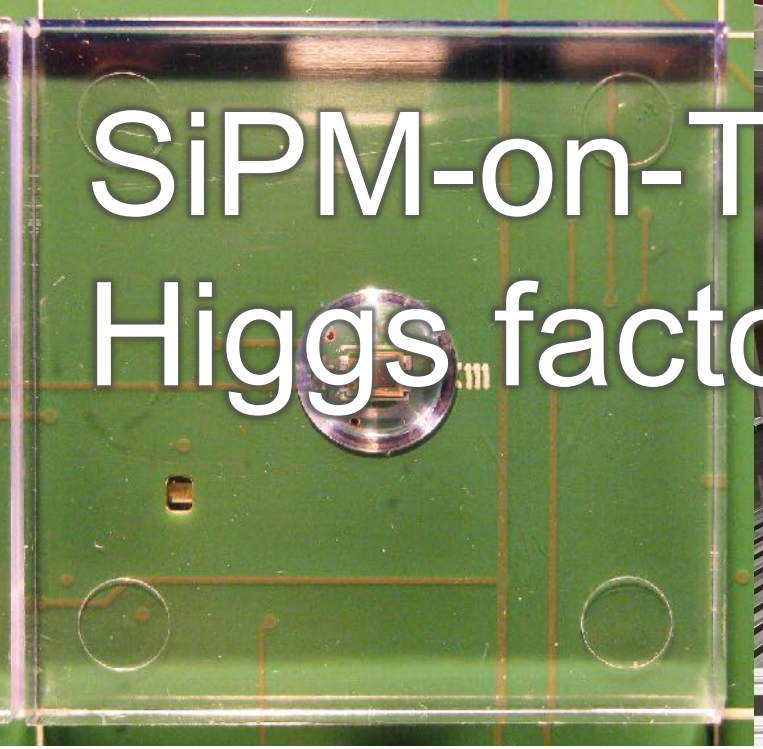
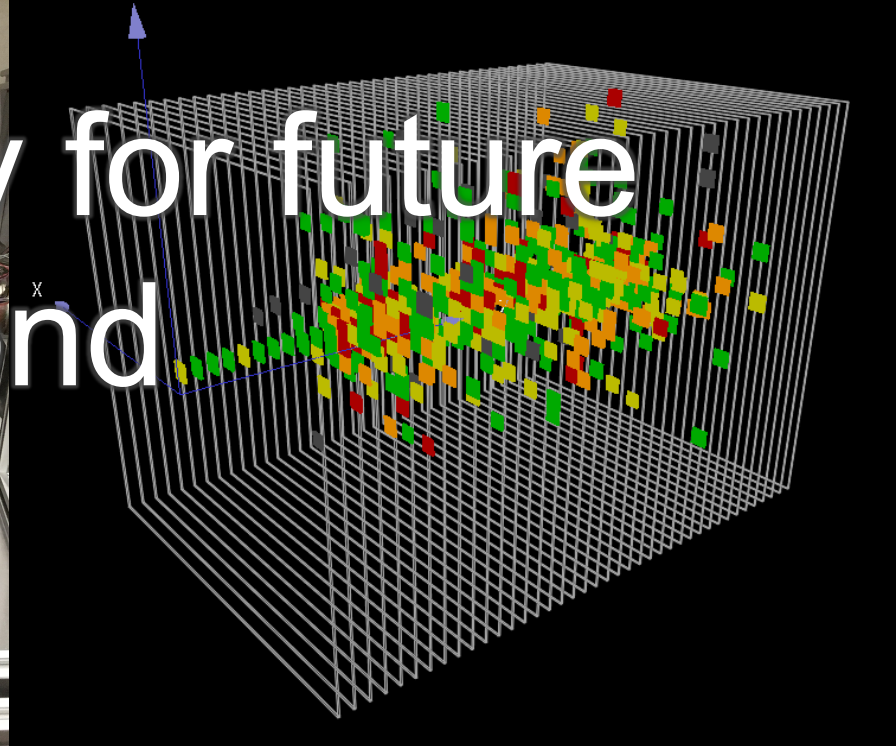




SiPM-on-Tile Calorimetry for future Higgs factories and beyond

Katja Krüger (DESY)

CPAD Instrumentation Frontier Workshop 2021
18 March 2021

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

CALICE

DESY.

Overview

- Motivation

- The CALICE Analog Hadron CALorimeter AHCAL
  - Physics Prototype
  - Engineering Prototype
  - Further Developments

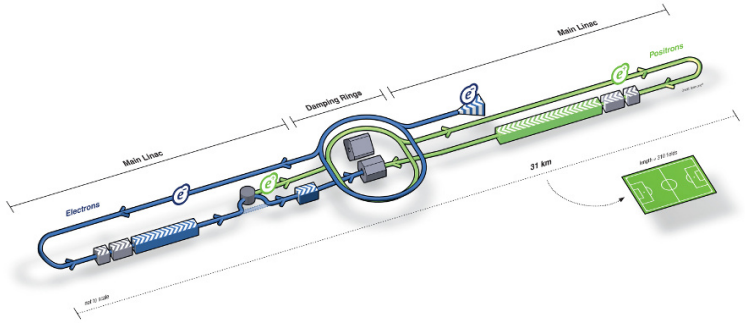
- SiPM-on-Tile technology beyond Higgs Factories
  - CMS HGCAL
  - DUNE Near Detector

- Summary

Motivation

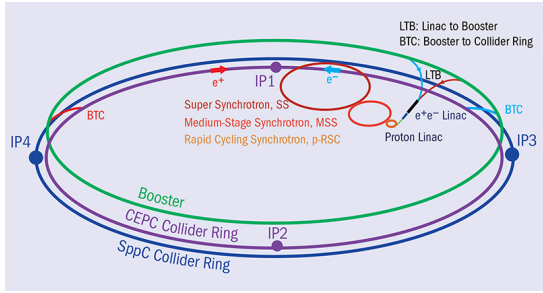
Higgs Factories

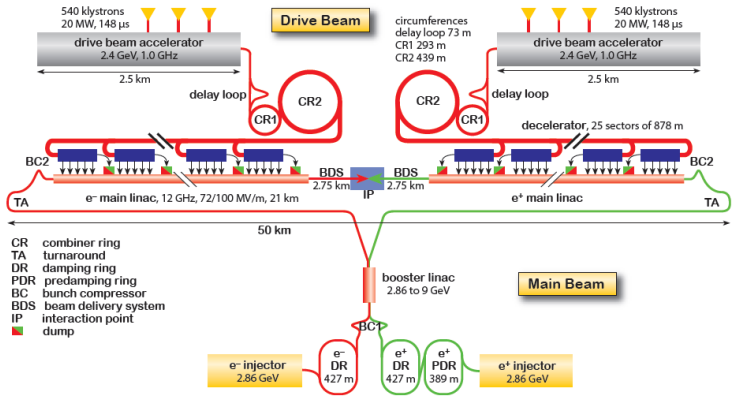
- European Strategy Update identified Higgs Factory as high priority
- Linear & Circular Proposals



ILC

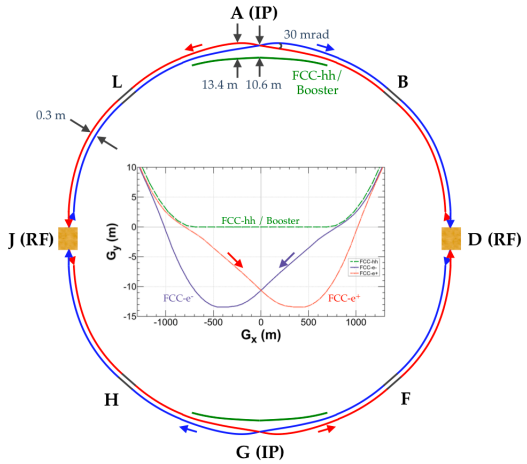
CEPC





CLIC

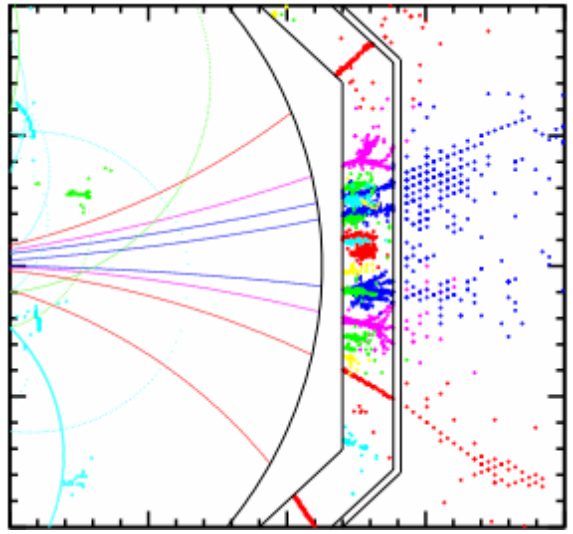
FCCee

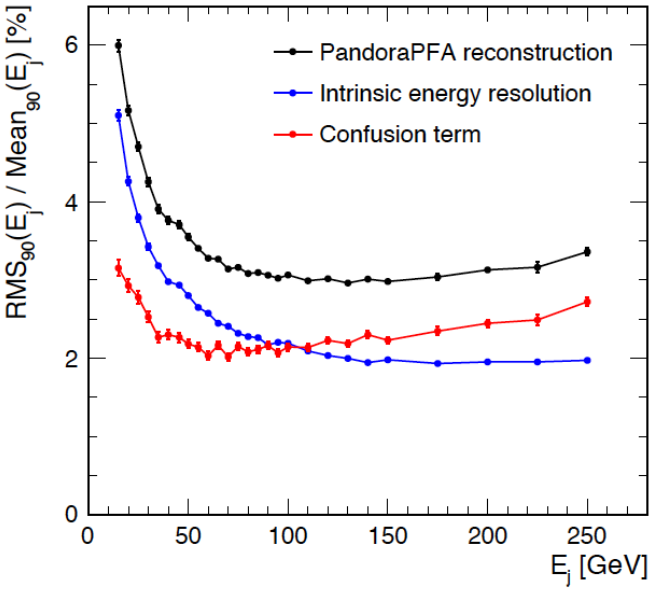


Calorimeters for Higgs Factories

- goal: want to distinguish Z → jet jet from W → jet jet
- requires σ(E)/E ≈ 3-4%
- can be reached by particle flow algorithms (PFA)
  - for each particle within a jet: use the subdetector with optimal resolution
  - need to avoid double counting and wrong merging
- need an imaging calorimeter!

- requirements for the calorimeter:
  - highly granular
  - reconstruction of neutral particles: good energy resolution
  - calorimeter has to be within magnet coil: very compact
- Scintillator tiles are a scalable, cost effective solution

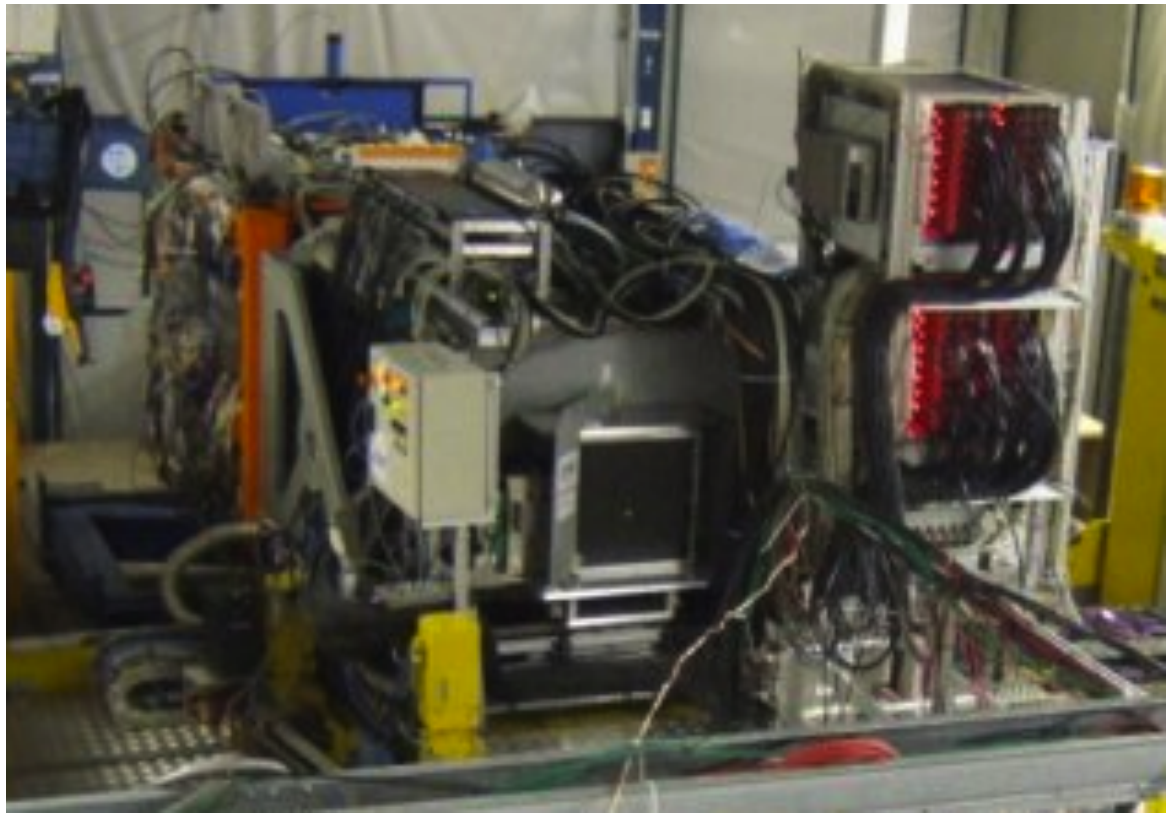


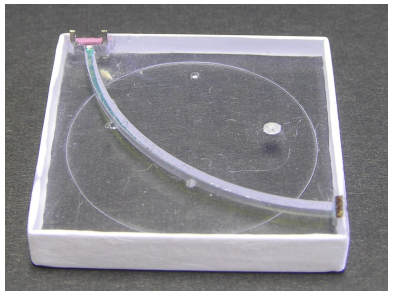


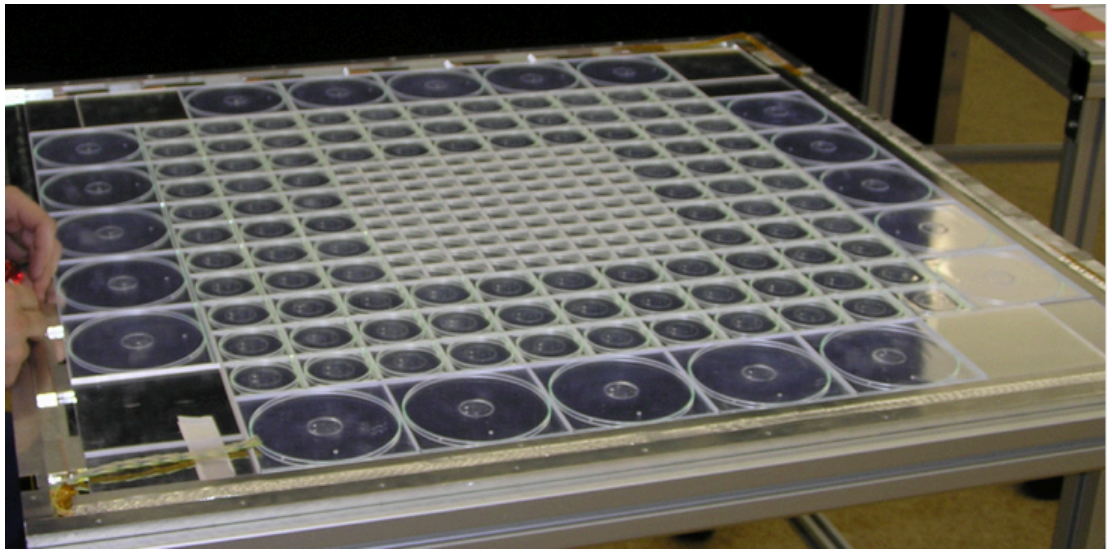
The CALICE AHCAL

The Origin: AHCAL Physics Prototype

- The first large calorimeter based on scintillator tiles read out by SiPMs
  - WLS fibers in each tile
- Tested in many testbeams 2006-2012

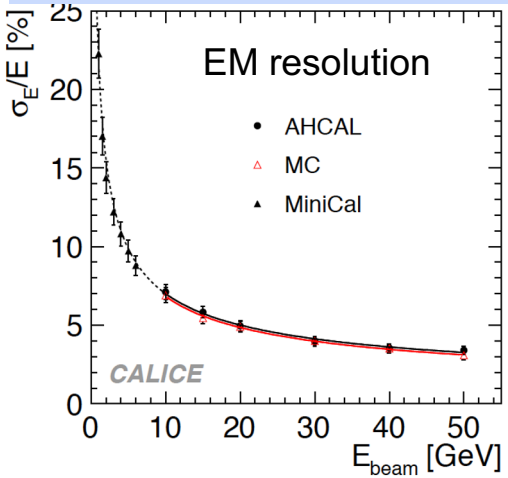






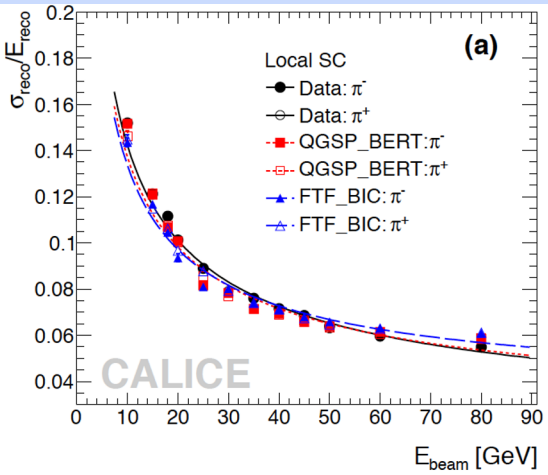
AHCAL Physics Prototype: Results

Detector validation



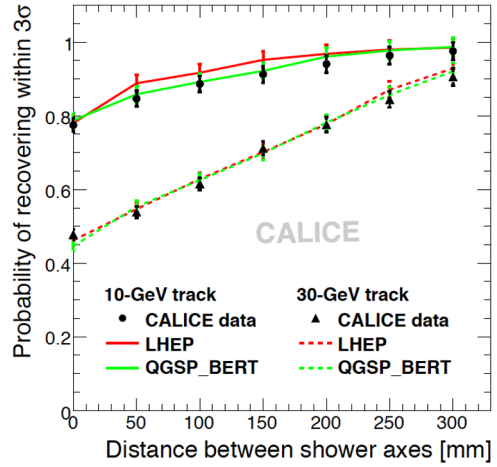
JINST 6, P04003 (2011)

Performance validation



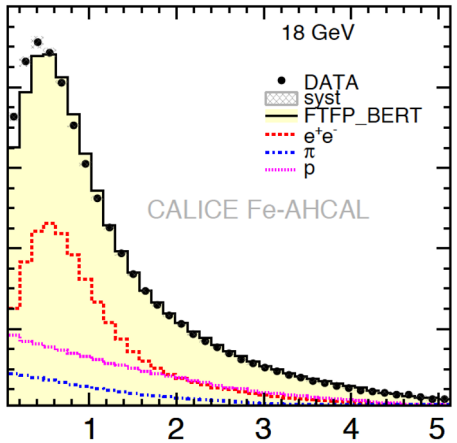
JINST 7, P00917 (2012)

Particle Flow validation



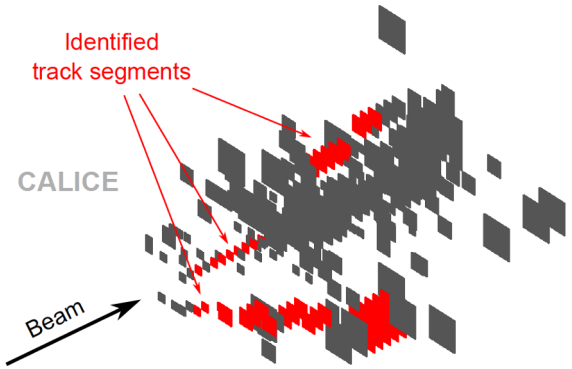
JINST 6, P07005 (2011)

Geant 4 validation



JINST 8, P07005 (2013)

Imaging validation



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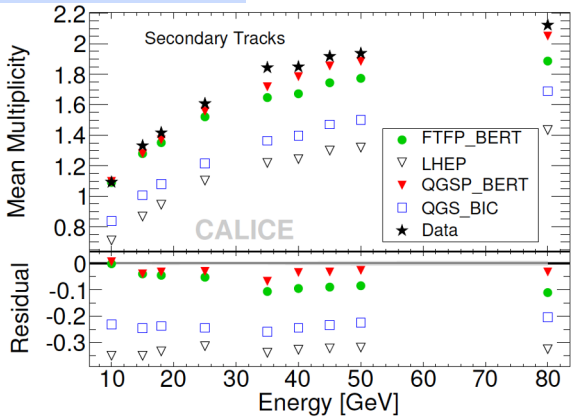
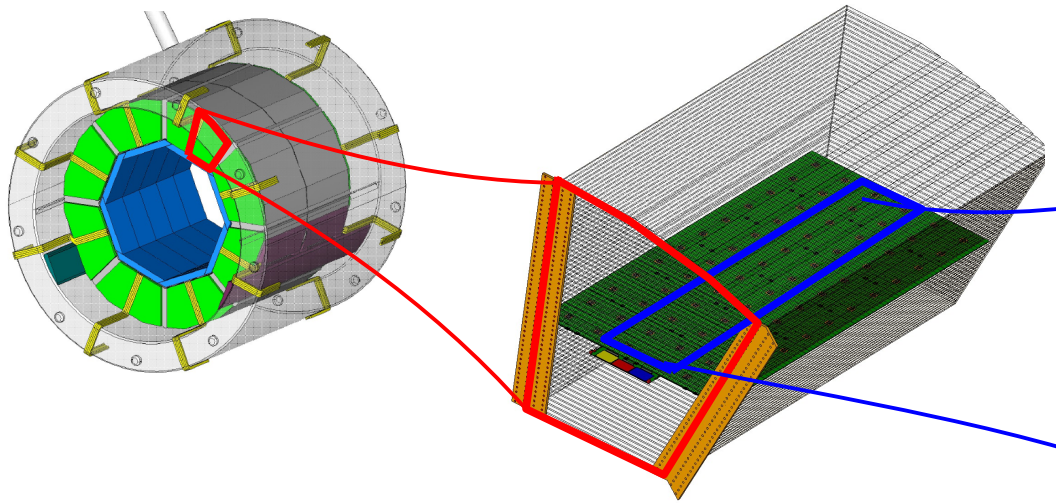
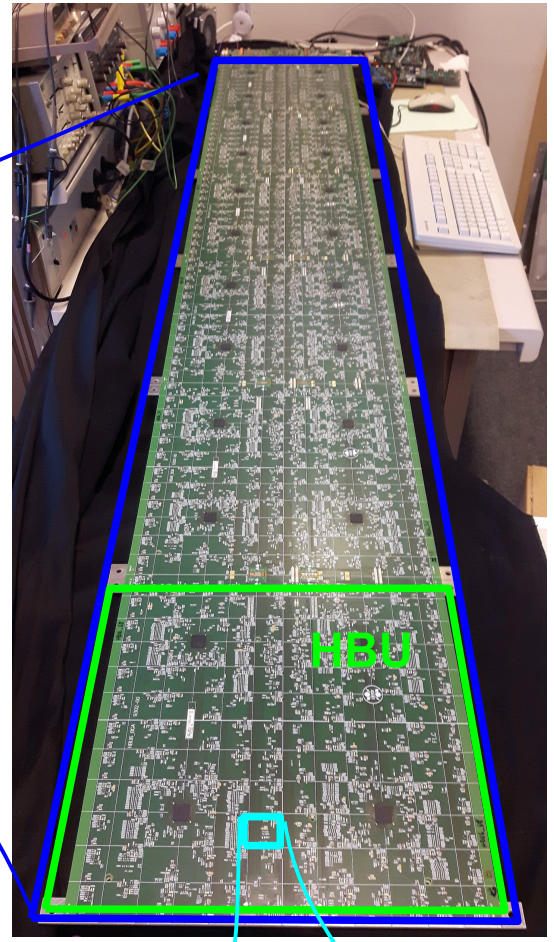
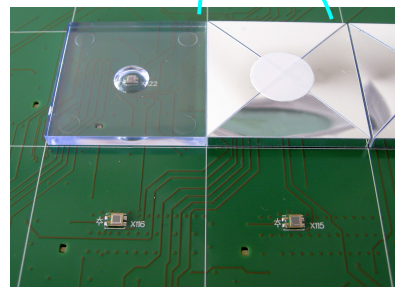


AHCAL Technological Prototype



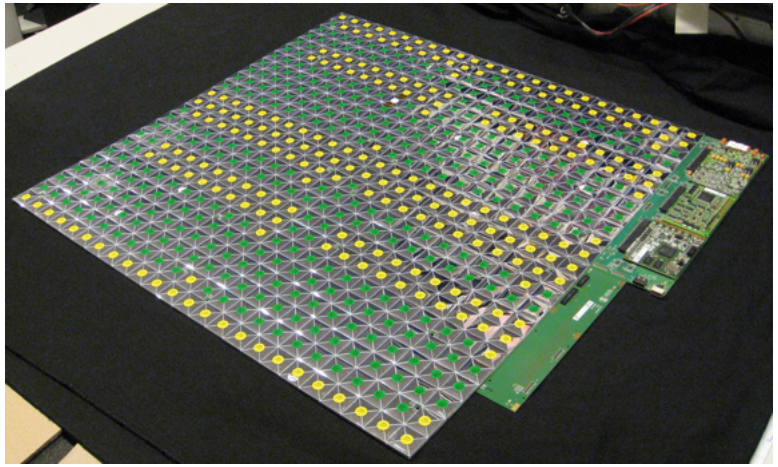




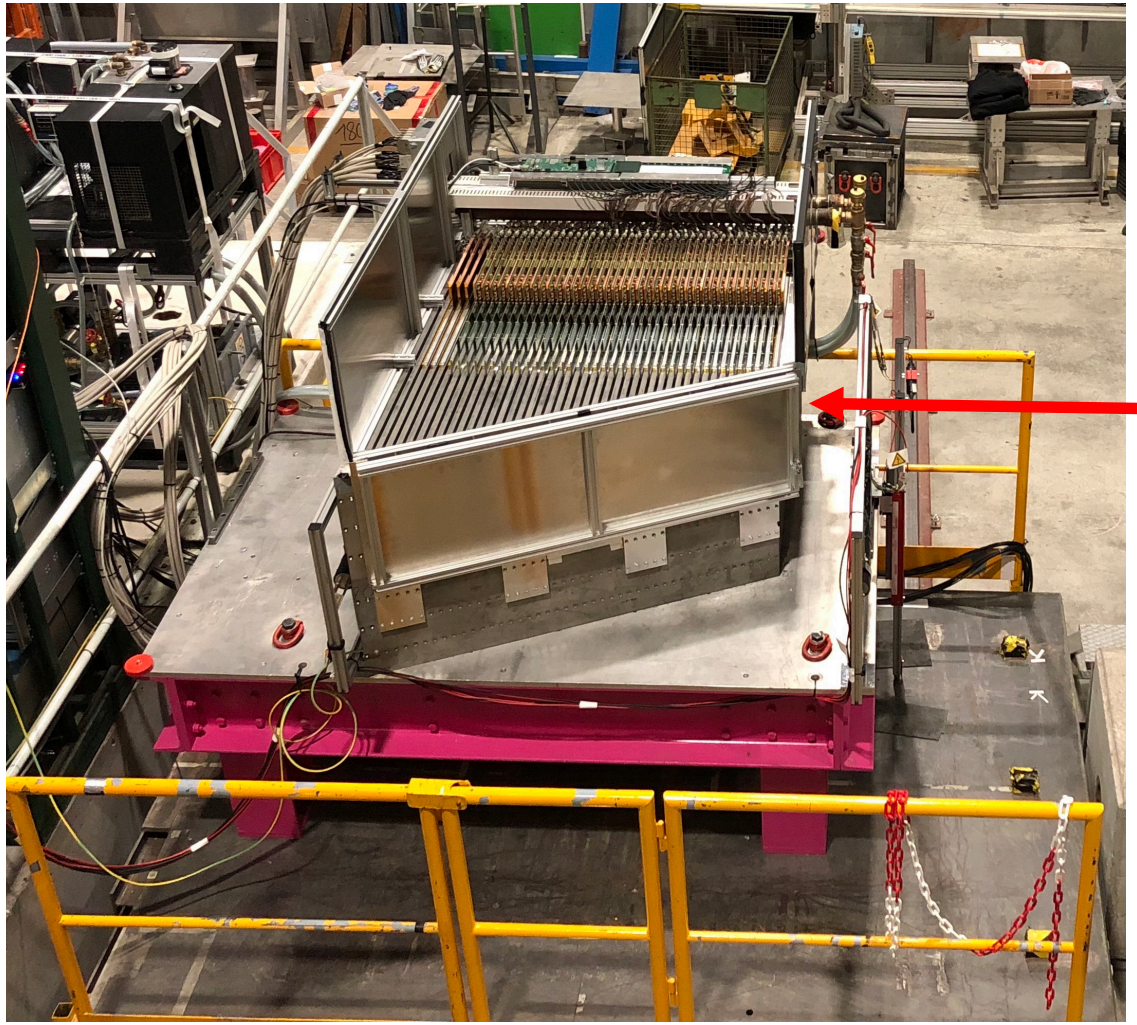
- highly granular scintillator SiPM-on-tile hadron calorimeter, 3*3 cm² scintillator tiles optimised for uniformity
- **fully integrated design**
  - front-end electronics, readout
  - voltage supply, LED system for calibration
  - no cooling within active layers -> **power pulsing**
- **scalable** to full detector (~8 million channels)
- geometry inspired by ILD, similar to SiD and CLICdp
- HCAL Base Unit: 36*36 cm^2, 144 tiles, 4 SPIROC2E ASICs
  - slabs of 6 HBUs, up to 3 slabs per layer

AHCAL Technological Testbeam Prototype

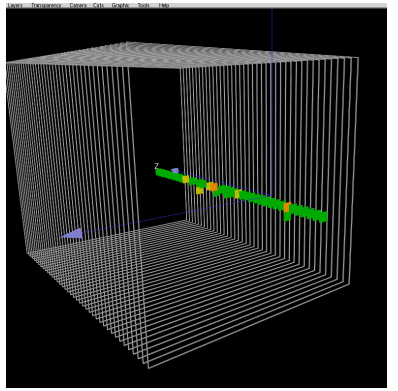
- Large enough to contain hadron showers
  - 38 active layers of 72*72 cm²
  - 4 HBUs per module
  - in total: 608 SPIROC2E ASICs, ~22000 channels
  - SiPMs: Hamamatsu S13360-1325PE
- All modules interchangeable
- Built with scalable production techniques in ~2 years
- Operated in beam tests with muons, electrons and pions at CERN SPS in 2018
  - 3 weeks of beam time
  - Collected O(100) mio events
  - Very stable running
  - Nearly noise free
  - < 1 per mille dead channels

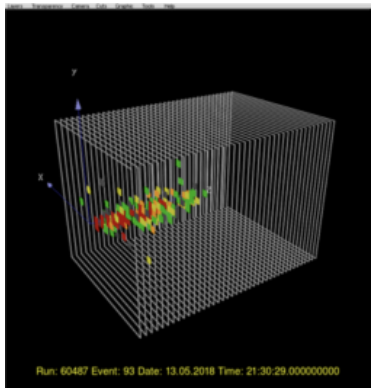


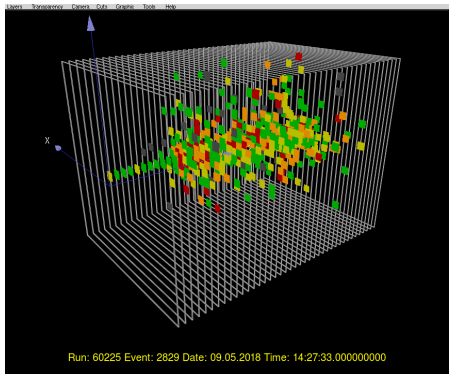
AHCAL Technological Trototype at SPS Testbeam



beam



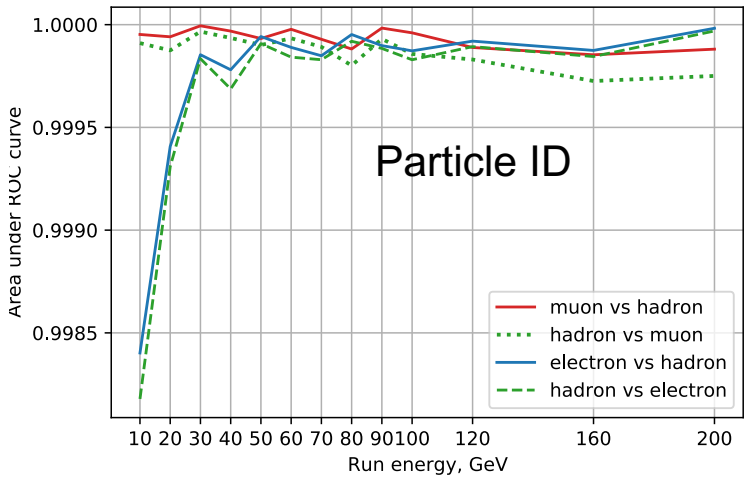


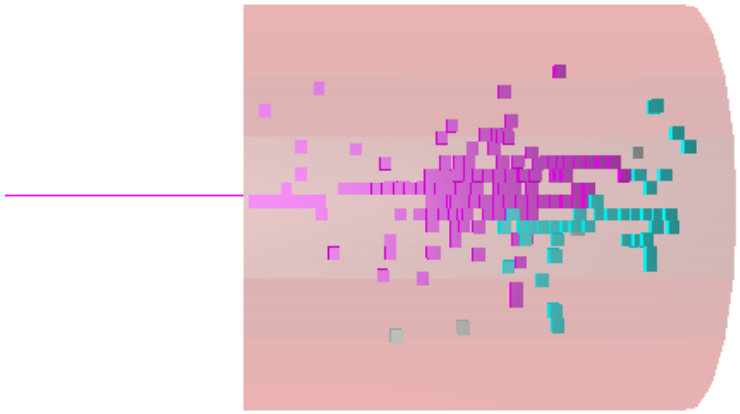


AHCAL Technological Prototype: Ongoing Analyses

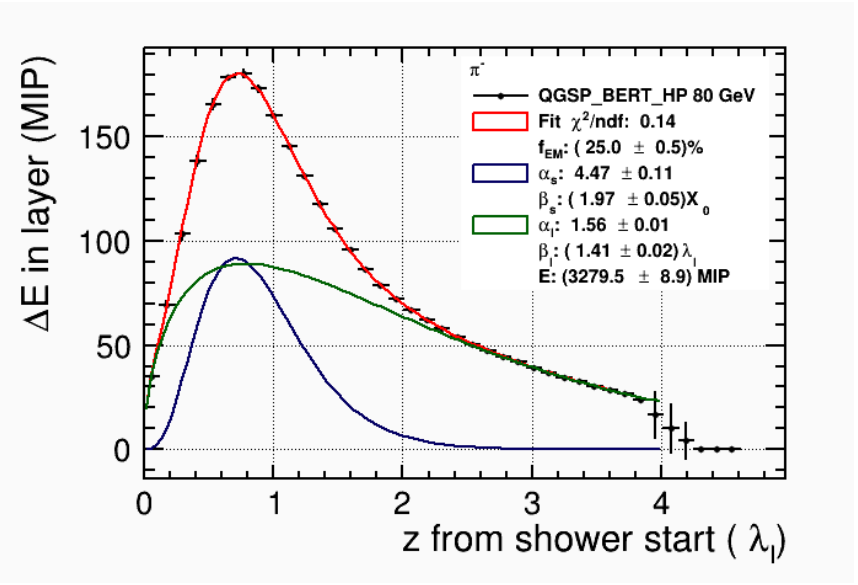
High granularity offers detailed look into hadron showers

- Used in particle ID based on Boosted Decision Trees
- Studies of shower shapes
- Application of the PandoraPFA Particle Flow Algorithm





Magenta: Charged Hadron
Cyan: Neutral Hadron
Grey: Unclustered Hits



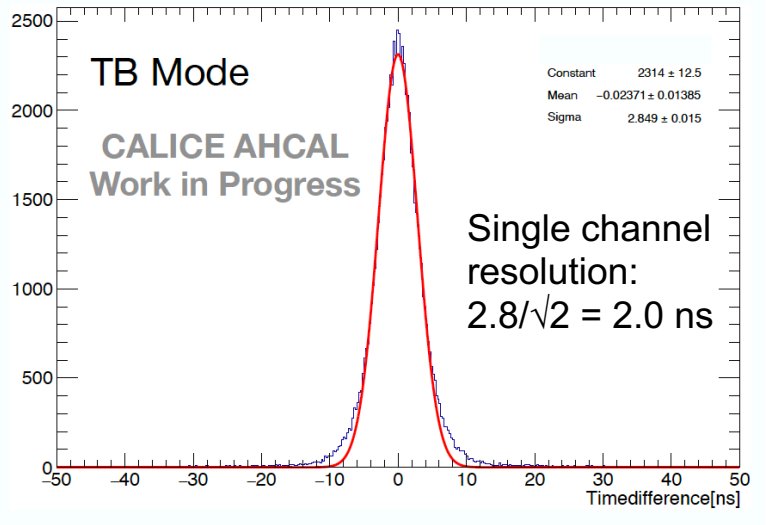
AHCAL Prototype: Hit Time Measurement

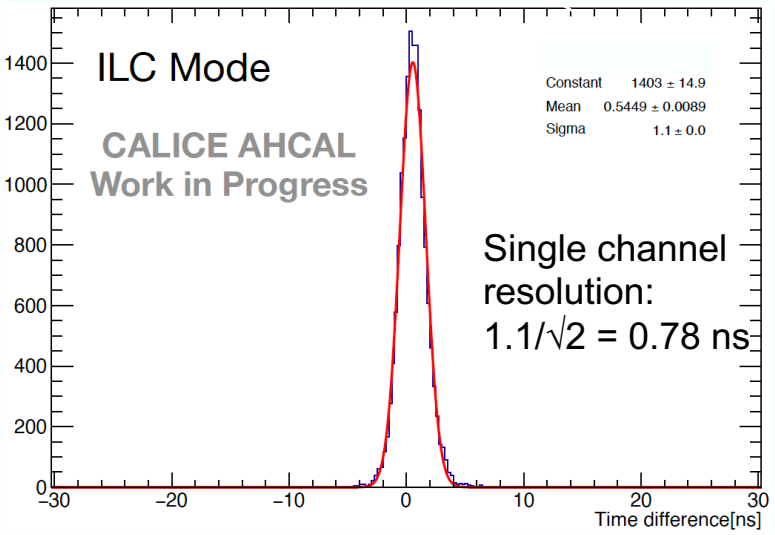
New feature in AHCAL technological prototype: time measurement for individual hits

- Design resolution: ~1 ns
- SPIROC2E readout ASIC supports 2 bunch clock speeds
  - Testbeam mode: 250 kHz clock
    - More efficient for data taking in testbeams
    - Worse hit time resolution: ~2ns
  - ILC mode: 5 MHz
    - Adapted to ILC bunch structure
    - Better hit time resolution: ~0.8 ns

- Full exploitation in data analysis just started

- Most testbeam data so far taken in testbeam mode





AHCAL Plans: Testbeam Measurements

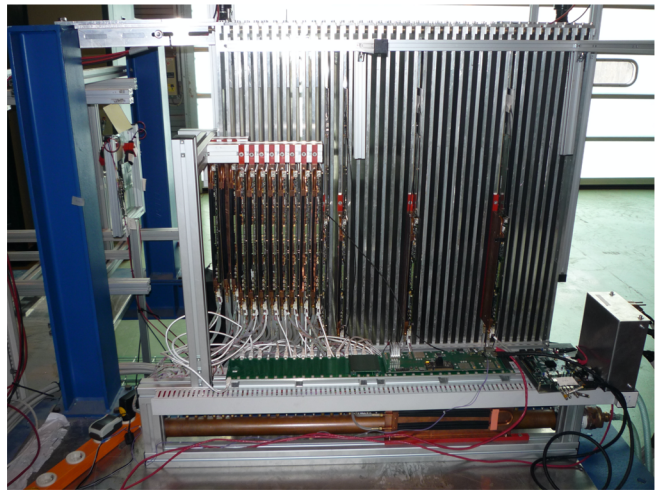
New collaborators welcome!

Fully exploit timing capabilities

- Perform full set of testbeam measurements in ILC mode
- Develop reconstruction algorithms to better use hit time information

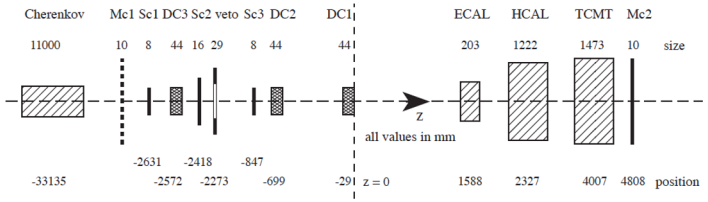
Tungsten Stack

- Data taken so far with steel absorber stack
- Tungsten would offer shorter showers
- Valuable input for hadronic shower models (ECAL)
- Plan to re-use tungsten absorber stack already used for physics protype



Running with ECAL

- Performance of a calorimeter system depends on combination of ECAL and HCAL
- Plan to take data together with CALICE silicon-tungsten and/or scintillator-tungsten ECAL

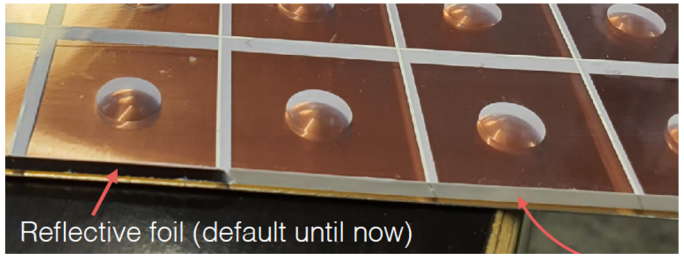


AHCAL Plans: Hardware Developments

New collaborators welcome!

Alternative scintillator geometry

- Megatiles would allow larger units for mechanical assembly
- Status: Ongoing effort, optimization of uniformity and cross talk

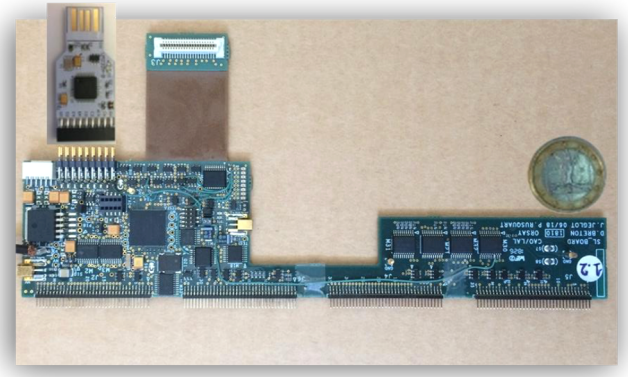


Alternative Readout ASIC (KLauS)

- Wide range of applications
- Possible application at circular Higgs factories
- Optimised for SiPMs with small pixels (10µm) -> possible application in ECAL
- Status: KLauS6 with full functionality available, ongoing effort to integrate into AHCAL DAQ

Common Readout

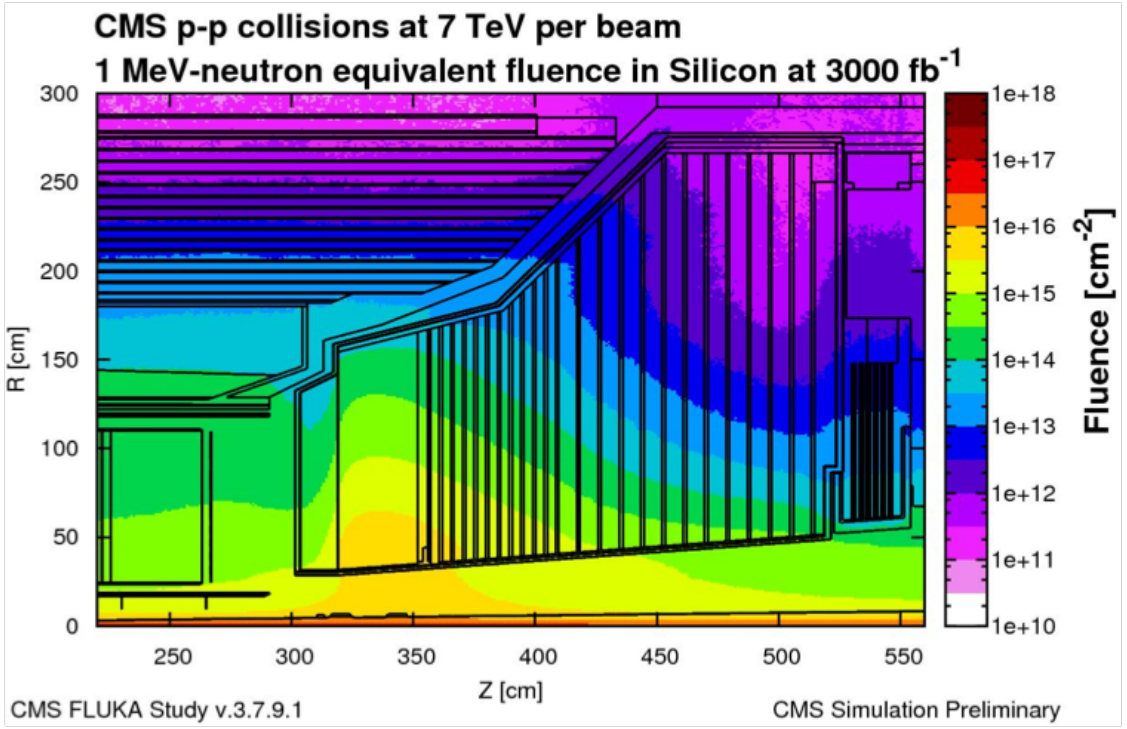
- Harmonise readout between CALICE SiW ECAL and AHCAL
- Status: just started



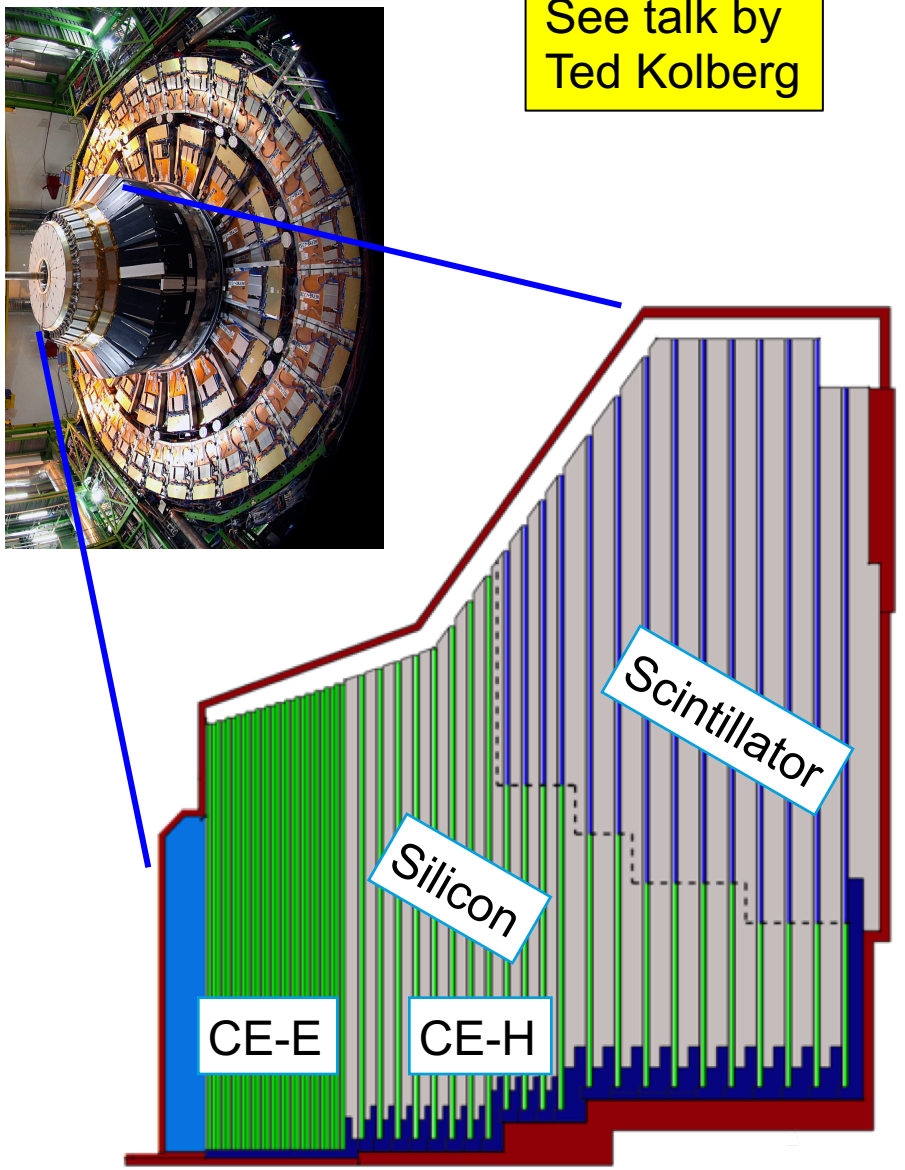
SiPM-on-Tile calorimetry beyond Higgs Factories

SiPM-on-Tile in CMS HGCAL

- CMS calorimeter endcap will be replaced for HL-LHC by **H**igh-**G**ranularity **cal**orimeter
- synergy with high granularity calorimeter concepts developed for electron-positron colliders
  - Use SiPM-on-tile wherever radiation levels allow



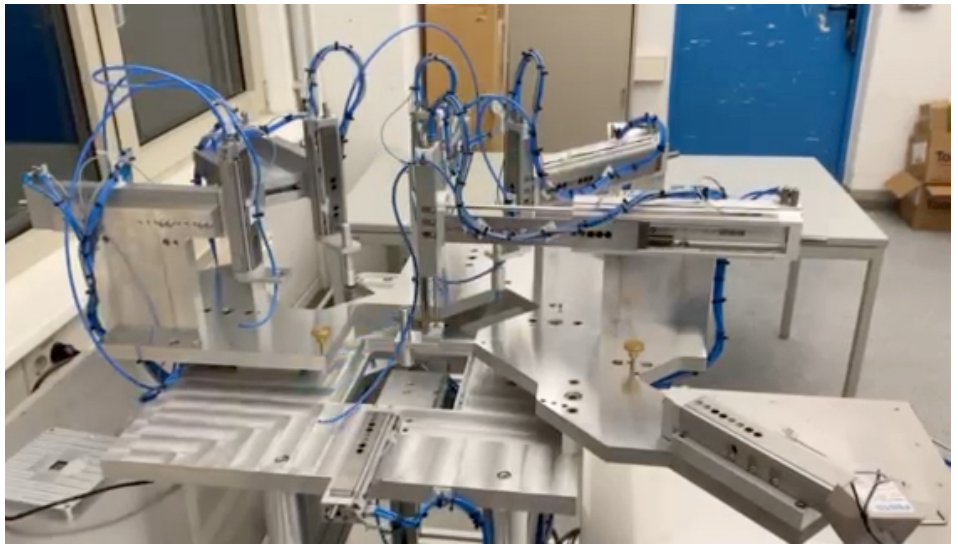
See talk by Ted Kolberg

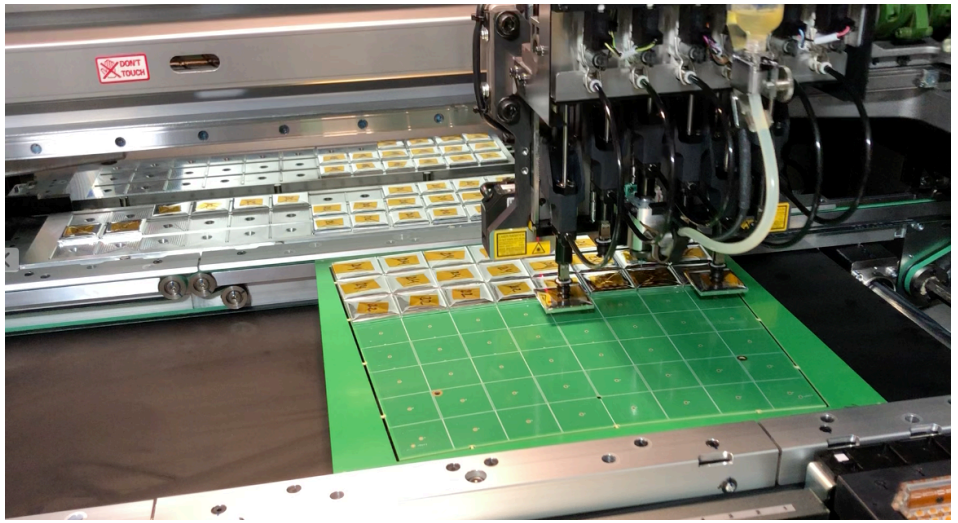


SiPM-on-Tile Technology for HGCAL

- New challenges:
  - radiation levels
  - data rates
  - operation at -30 degrees
  - Many different tile and board sizes

- Adaptation of AHCAL technologies to HGCAL
  - Readout with fast and rad-hard components
  - Careful design for large temperature variations (from assembly to operation)
  - More flexible and robust assembly procedures
    - Tile wrapping
    - Tile glueing

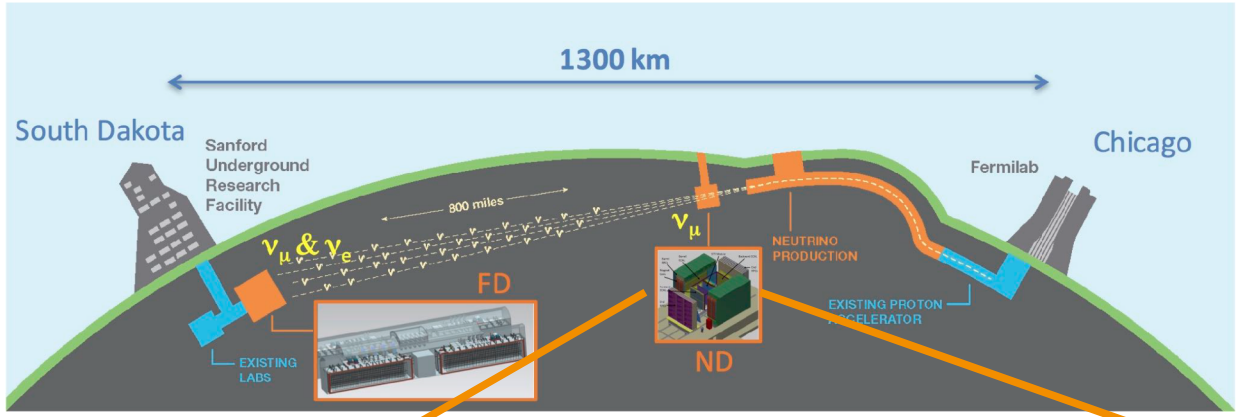


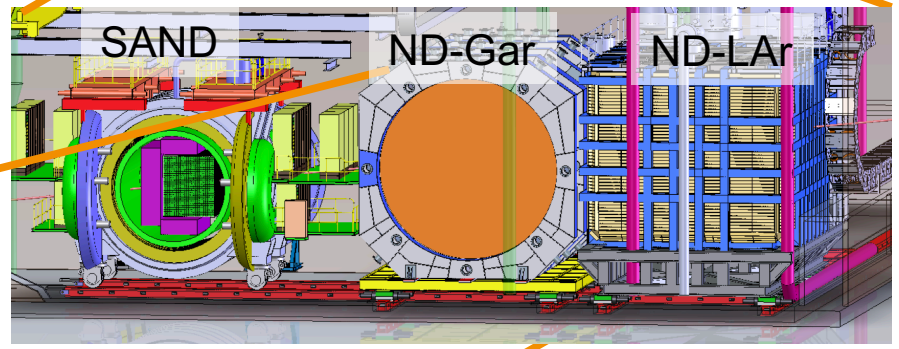


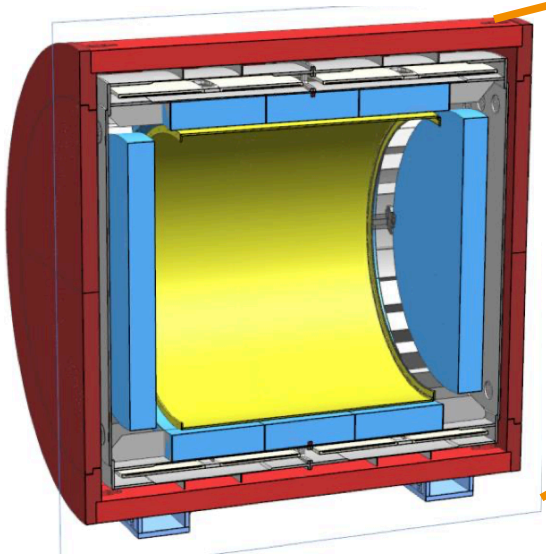
Deep Underground Neutrino Experiment

- DUNE Far Detector: Study neutrino oscillations
  - Large LAr TPCs

- Near Detector (ND): measure beam before oscillation
  - DUNE PRISM: 3 detectors of which 2 can be moved off-axis
  - ND-LAr: Liquid Argon TPC
  - **ND-GAr: High Pressure GAr TPC, surrounded by ECAL and magnet**
  - SAND: plastic scintillator target





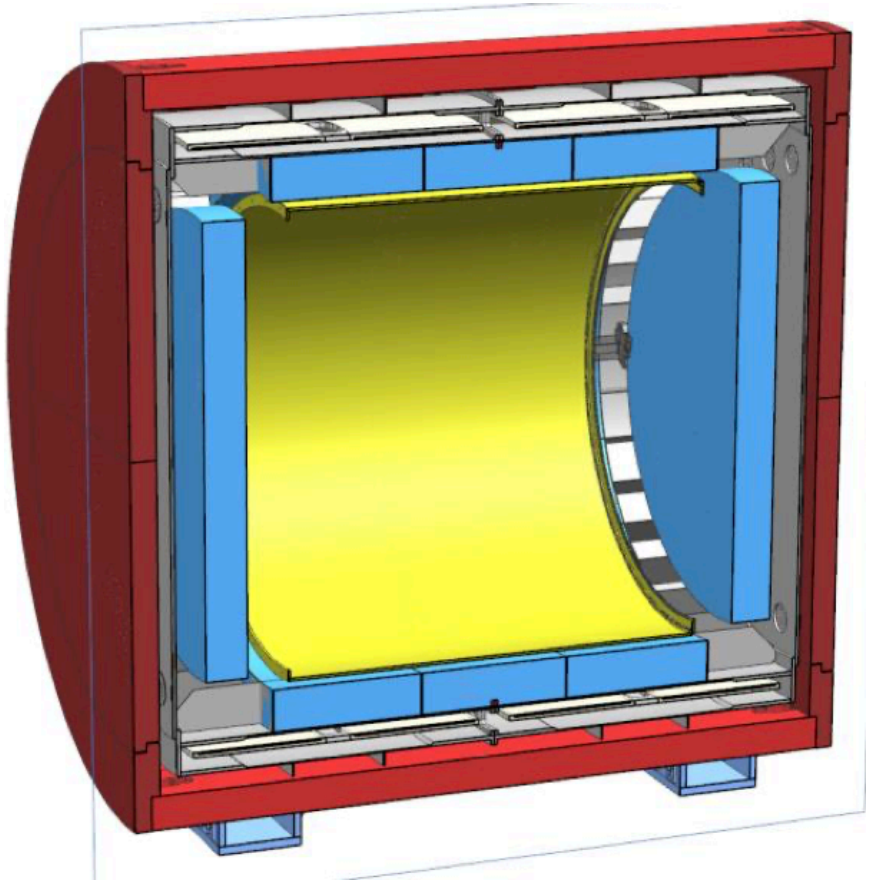


SiPM-on-Tile for DUNE ND-GAr

ND-GAr

- Gaseous Argon TPC surrounded by ECAL and magnet
- Lower energy threshold than liquid Argon -> better to distinguish some models
- goal: detect π^0 from neutral current interactions and neutrons from interactions of neutrinos with Argon nuclei
  - typical energies of a few 100 MeV
  - need good energy and direction measurement

- Large sampling ECAL with good energy and angular resolution, neutron sensitivity and sub-ns time resolution
  - Scintillator tiles and strips directly readout by SiPMs
  - New challenges:
    - Very low energies -> very thin absorber
    - Very large area -> incorporate strips
    - Neutron sensitivity



Summary

- SiPM-on-Tile calorimetry offers high granularity and good energy resolution at reasonable cost
- Performance demonstrated with CALICE AHCAL physics prototype
- Engineering design demonstrated with CALICE AHCAL technological prototype
- SiPM-on-Tile technology can be adapted to different conditions
  - CMS HGCAL
  - DUNE Near Detector
- Open for new ideas, e.g. timing information in compensation methods

- **Active community, new collaborators welcome!**

Thank you!